SMALL PUNCH TESTING OF ADVANCED METAL MATRIX COMPOSITES

A dissertation submitted in fulfilment
of the requirements for
the degree of
Doctor of Philosophy

By
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For my loving parents

Mak Shu Kai and Mak Cheuk Ping

I know that the molecules in my body are traceable, to phenomenon in the cosmos, and it's out of 15 pounds of grey-matter that figured this out! The kingship with the cosmos that resinates deeply with new age thinking... But I'm not apologetic about that, it's what we find, if whatever we find resinates with whomever. Go ahead take it!

I want somebody to put electrodes on my head, and when I reflect on, our kingship with the cosmos, when I do the calculations that shows, that a 15 tonne meteorite that we have in the Rose Centre for Earth and Space, it's an iron meteorite, when I do the calculations that shows, that if you take all the iron from the haemoglobin of the people in Tri-State Area of New York City. You can recover that much iron out of their blood and realise that the iron from that meteorite and iron from your blood has

Common origin! In the core of a star!

Tell me what part of my brain is lighting up because that excites me. That makes me want to grab people in the street and say "have you heard this"??

It's quite literally true that we are stardust… In the highest exalted way that one can use that phrase.

When it was announced that we were going to cancel the Hubble Telescope the greatest outcry to not do that was not the Astrophysicist, it wasn't from within NASA, it was the public. It was all over the op-ed pages and the talk shows. The public took ownership of the Hubble Space Telescope because the Universe was coming into their bedroom, into their living room and onto their computer. They were participants on the frontiers of discovery. And as far as I can tell, if you let them know, that we're not just something in the Universe, but in fact, given the Chemistry of it all and the Nuclear Physics of it all. Not only are we in the Universe, the Universe is in us…

And, I don't know, any deeper spiritual feeling, than what that brings upon me.

Neil deGrasse Tyson
Beyond Belief Conference, 2006

ABSTRACT

This Doctoral thesis investigates the use of the small punch test (SPT) as a means for assessing yield strength and fracture toughness from alloys and metal matrix composites (MMCs). Metal matrix composites have been implemented in many high performance applications due to their high strength to weight ratio, however, low fracture toughness and ductility remain a concern for these materials. Therefore, techniques for conventional mechanical tests including tensile and fracture toughness tests have been utilised to assess the mechanical performance for these materials, however, more often than not, situations will arise where there are limited volumes of material for testing, this is especially true in the case of MMCs. Thus, there is great demand for mechanical tests that are capable of assessing small samples. The small punch test (SPT) is proposed as a suitable small specimen mechanical test technique that is capable to meet this challenge. This research examines the SPT on MMCs and the effect of ceramic reinforcement content on yield strength and fracture toughness. To achieve this small punch, tensile and fracture toughness tests are performed on as-received 7A04-T6 aluminium and TC4 titanium alloy and related MMCs. In particular, small punch values such as the small punch elastic-plastic load, P_y, equivalent fracture strain, ε_{qF}, and small punch energy, E_{SP}, are correlated against conventional tensile yield strength, σ_{YS}, and plane-strain fracture toughness, J_{1c}, values. Furthermore, empirical, analytical and numerical solutions are assessed. A polynomial relationship is found to correspond well with J_{1c}-ε_{qF} relationship for both elastic and elastic-plastic materials. This research further investigates and develops the application of the SPT which may lead to an inexpensive straightforward multi-mechanical non-destructive test technique for advanced alloys and MMCs.

CERTIFICATE OF AUTHORSHIP

I certify that the work on this thesis has not previously been submitted for a degree nor has it been submitted in part of the requirements for a degree except when fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are acknowledged within this thesis.

Candidature's Signature

Dated: 30-June-2011

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LIST OF SYMBOLS

Symbol	Unit	Description
r_o	mm	Small punch ball radius
R_u	mm	Small punch hole radius of the upper die
R_l	mm	Small punch hole radius of the lower die
r^*	mm	Small punch chamfer edge
d_o	mm	Small punch specimen diameter
t_o	mm	Small punch specimen thickness
t_f	mm	Small punch minimum thickness at fracture
r'	mm	Small punch equivalent contact radius
δ^*	mm	Small punch displacement at fracture
δ_y	mm	Small punch elastic-plastic displacement
P_y	N	Small punch elastic-plastic load
P_i	N	Small punch load at crack initiation
P_{max}	N	Small punch maximum load
E_{SP}	J	Small punch fracture energy
ε_{qF}	-	Small punch equivalent fracture strain
σ_y	MPa	Small punch maximum bend strength
α	-	Small punch correlation coefficient
σ_{YS}	MPa	Yield strength
σ_{UTS}	MPa	Ultimate tensile strength
E	GPa	Elastic modulus
ν	-	Poisson's ratio
J_{1c}	kJ/m^2	Ductile plane-strain fracture toughness
K_{1c}	$MPa\sqrt{m}$	Brittle plane-strain fracture toughness
n	-	Strain hardening exponent